Impacts of the Atlantic Multidecadal Variability on the Tropical Pacific – At the origins of the inter-model spread

Yohan Ruprich-Robert (BSC)

Xavier Levine, Eduardo Moreno-Chamarro, Christophe Cassou, Frederic Castruccio, Rosie Eade, Guillaume Gastineau, Leon Hermanson, Dan Hodson, Katja Lohmann, Jorge Lopez-Parages, Paul-Arthur Monerie, Dario Nicoli, Said Qasmi, Chris Roberts, Emilia Sanchez-Gomes, Alessio Belucci, Gokhan Danabasoglu, Nick Dunstone, Marta Martin del Rey, Rym Msadek, Jon Robson, Doug Smith

Primavera General Assembly 2020, Reading (online)

EXCELENCIA SEVERO OCHOA

Barcelona Supercomputing Center
Centro Nacional de Supercomputación

MARIE CURIE ACTIONS

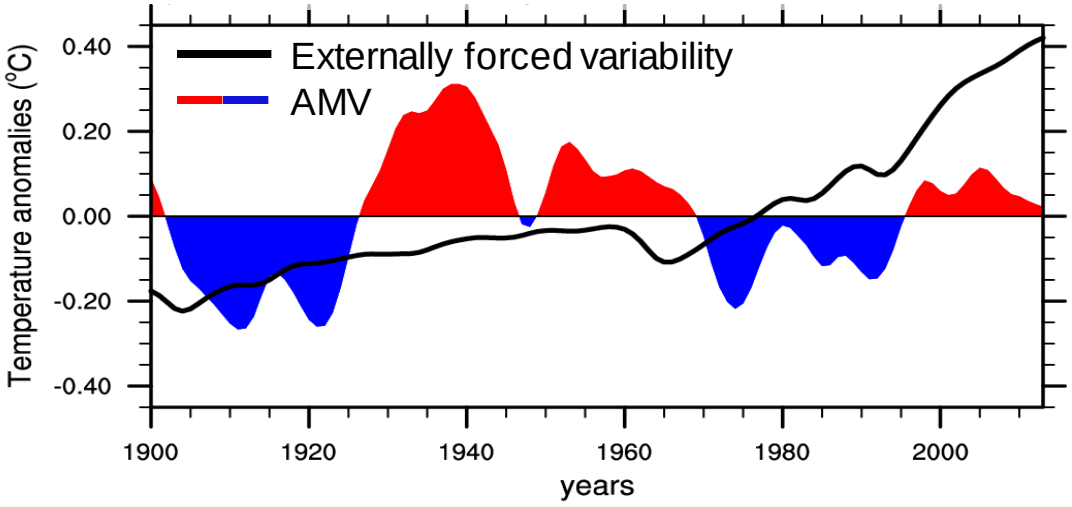
PRIMAVERA

INADEC: H2020-MSCA-800154

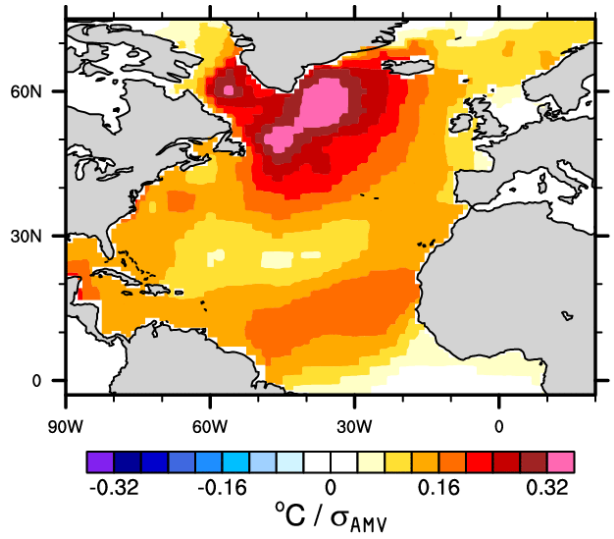
Linked between observed AMV and tropical Pacific

Atlantic Multidecadal Variability (AMV)

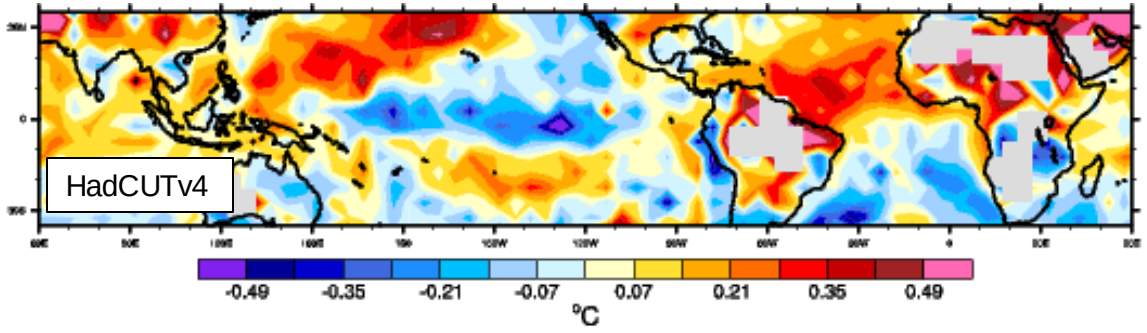
North Atlantic SST time series (Ting et al. 2009)



Observed AMV pattern



2m temperature – Observed AMV composites: DJFM



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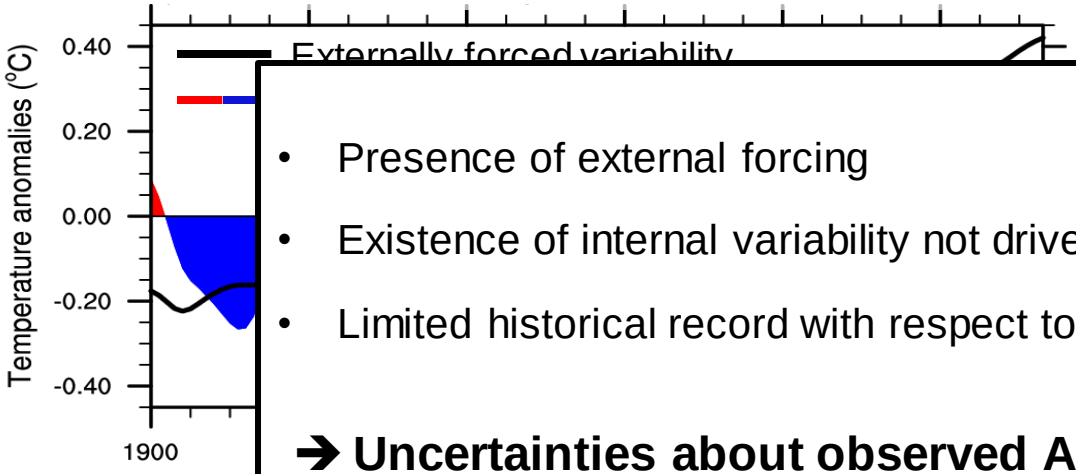

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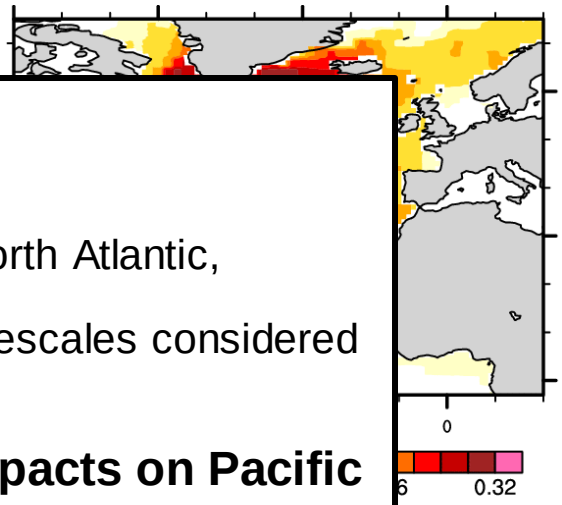
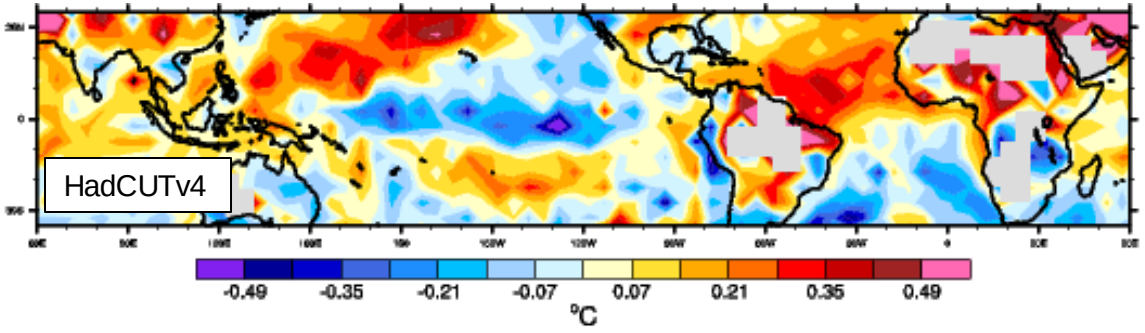


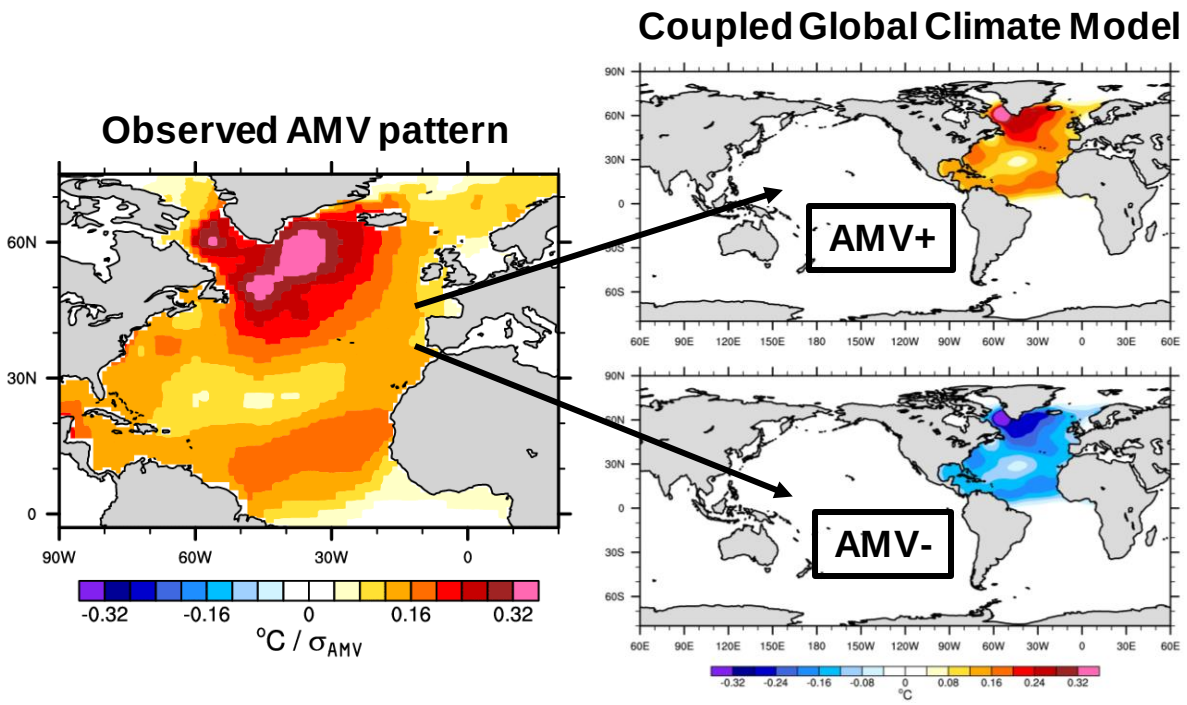
- Presence of external forcing
- Existence of internal variability not driven by North Atlantic,
- Limited historical record with respect to the timescales considered

➔ **Uncertainties about observed AMV impacts on Pacific**

2m temperature – Observed AMV composites: DJFM



Targeted numerical experiments: the idealized AMV simulations



Protocol:

Observed AMV pattern anomalies imposed over CGCM N. Atlantic

Free ocean-ice-land-atmosphere interactions outside of N. Atlantic

10yr long large ensemble experiments

- **Total of 23 sets of simulations (from 15 CGCMs)**
- 1xAMV forcing (9)
- 2xAMV forcing (9) + (2) SLAB ocean
- 3xAMV forcing (3)

Protocol adopted by Decadal Climate Prediction Panel of CMIP6 (Boer et al. GMD 2016)

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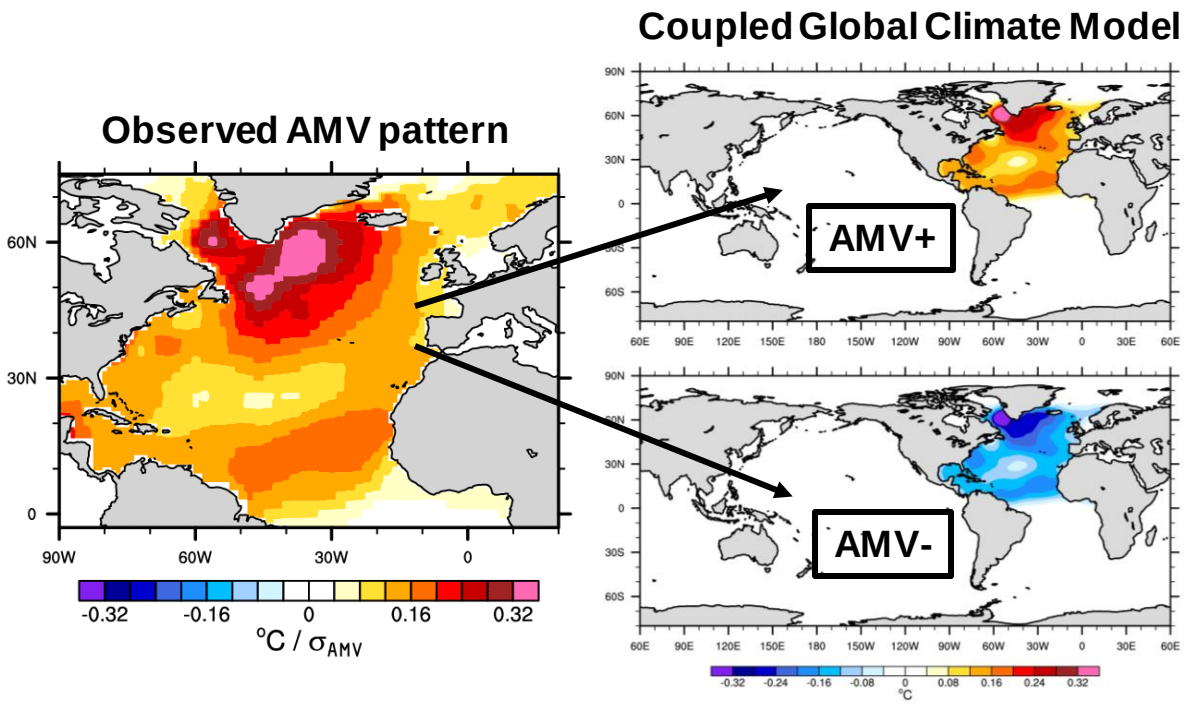

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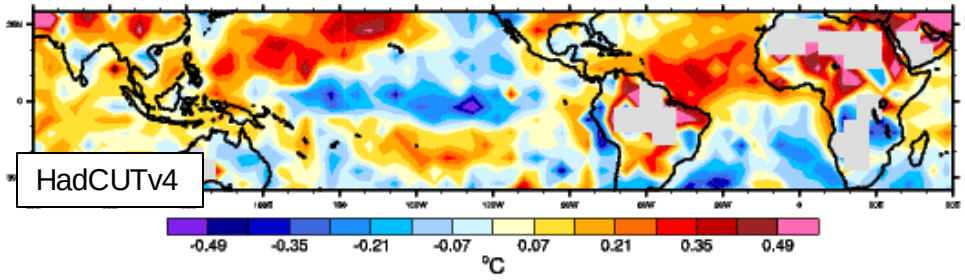
Primavera

Protocol adopted by Decadal Climate Prediction Panel of CMIP6 (Boer et al. GMD 2016)

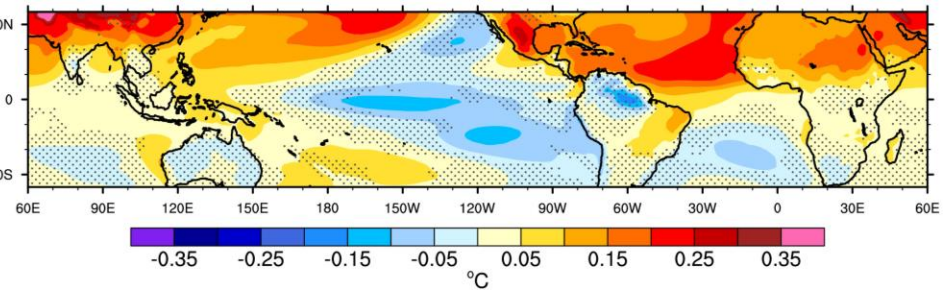
Multi-Model Mean confirms observed AMV – Pacific link…

T2m – Observed AMV composites: DJFM



T2m – MMM AMV+ - AMV-: DJFM

(10yr averaged ensemble mean)

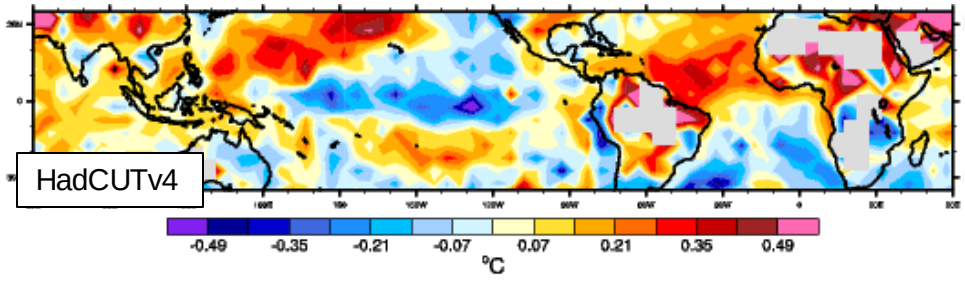


MMM = Multi Model Mean

T2m = 2-meter air temperature

… but large inter-model spread

T2m – Observed AMV composites: DJFM



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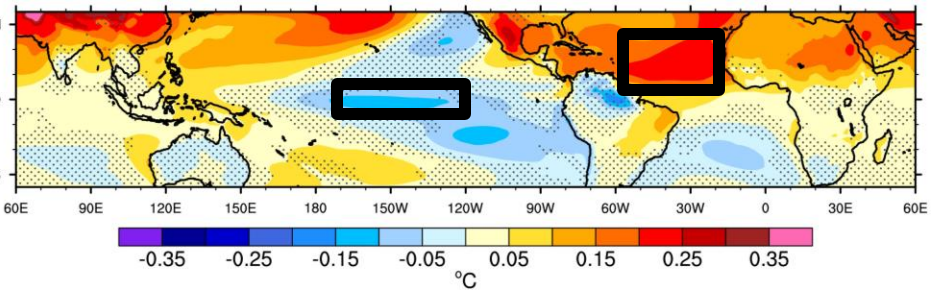

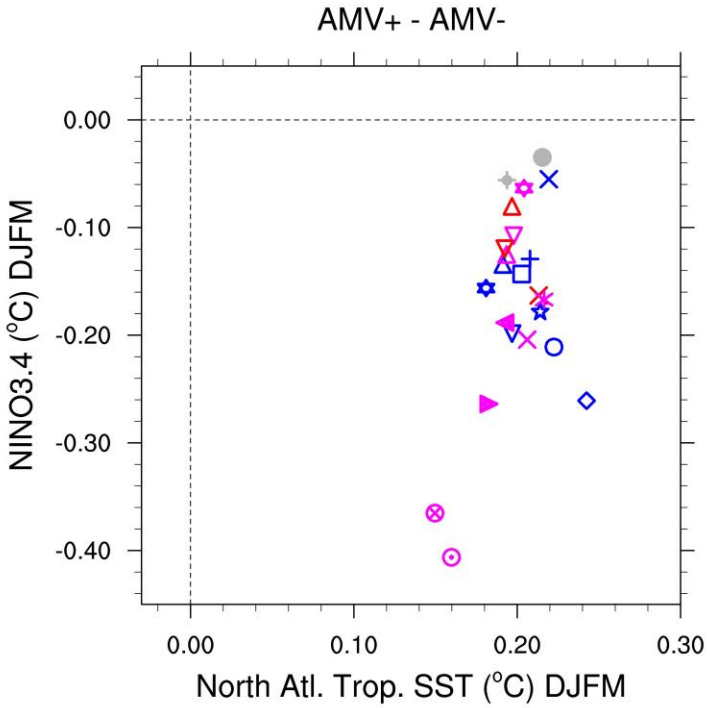

- CESM1
- CMCC-CM2
- CNRM-CM5_18_1
- CNRM-CM5_18_2
- CNRM-CM5_18_3
- CNRM-CM5_20_1
- CNRM-CM5_20_2
- CNRM-CM5_20_3
- CNRM-CM6_1
- CNRM-CM6_2
- EC-Earth3
- EC-Earth3P-HR
- EC-Earth3P_1
- EC-Earth3P_2
- EC-Earth3P_3
- ECMWF-HR
- ECMWF-LR
- HadGEM3
- IPSL-CM6
- MPI-ESM1-HR
- MPI-ESM1-XR
- MetUM-GOML-HR
- MetUM-GOML-LR

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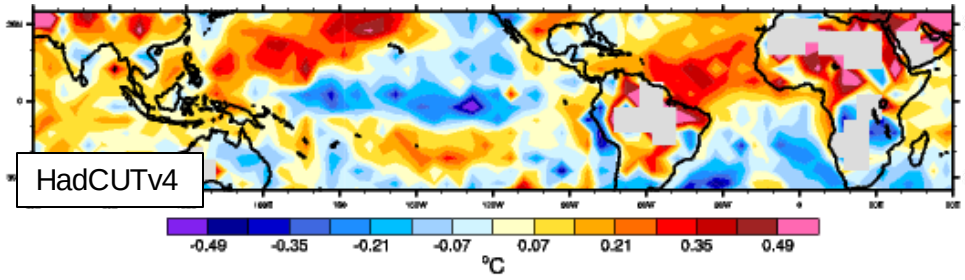
Origins of the inter-model spread?

T2m – Observed AMV composites: DJFM



T2m – MMM AMV+ - AMV-: DJFM

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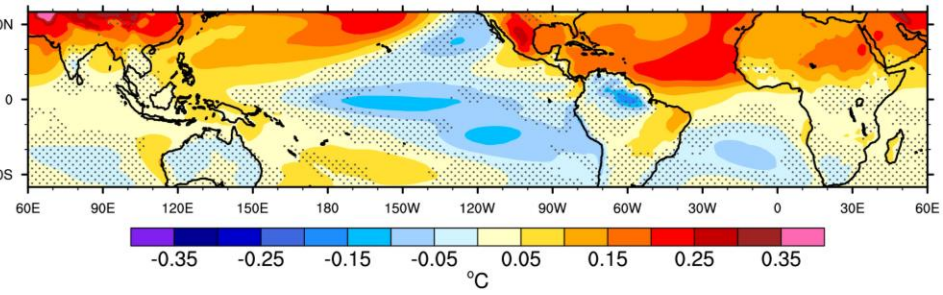

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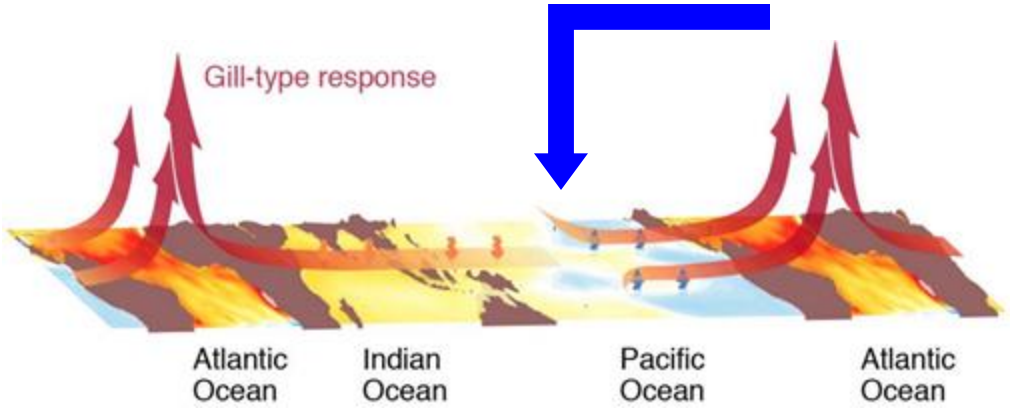
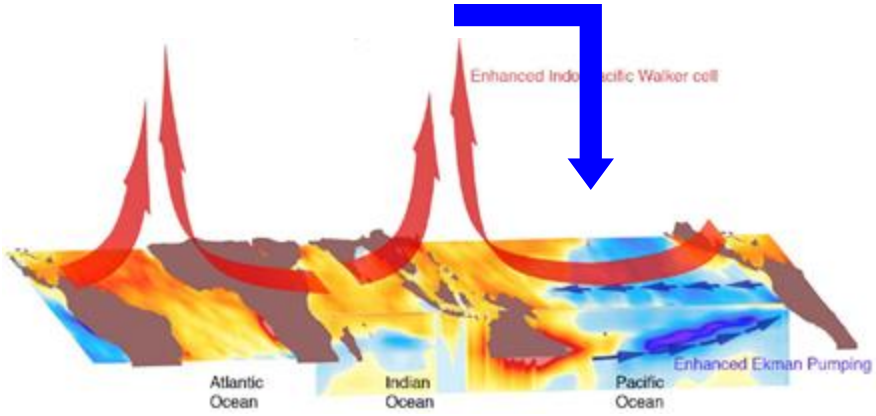
Phase-1: Atlantic forcing



Phase-2: Indo-Pacific feedback



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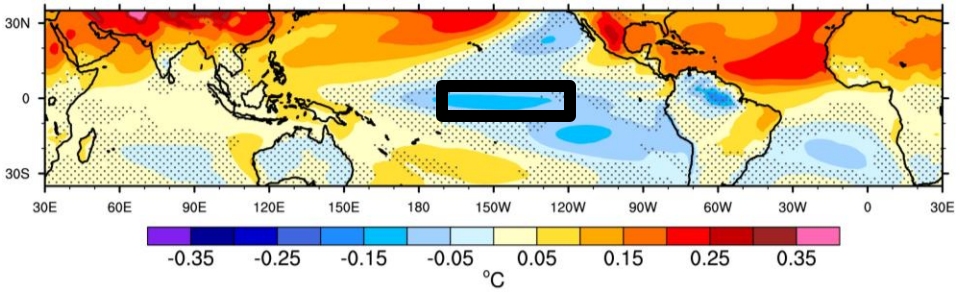
1) Is the winter Pacific response linked to summer Pacific conditions?

Inter-model correlation of -0.87 between DJFM NINO3.4 and JJAS Trop. Pac. subsidence ✓

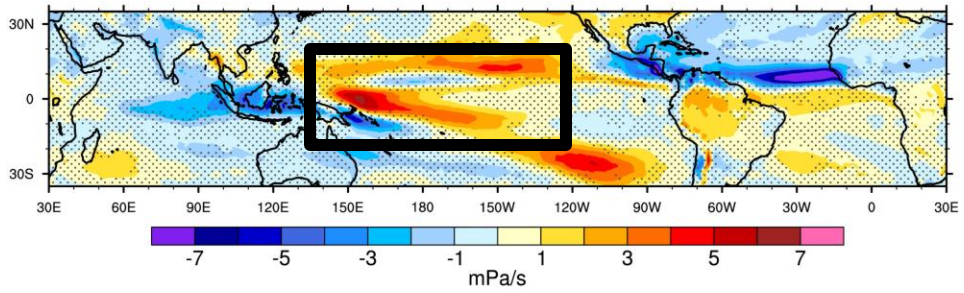
MMM AMV+ - AMV-
(10yr averaged ensemble mean)

DJFM – T2m

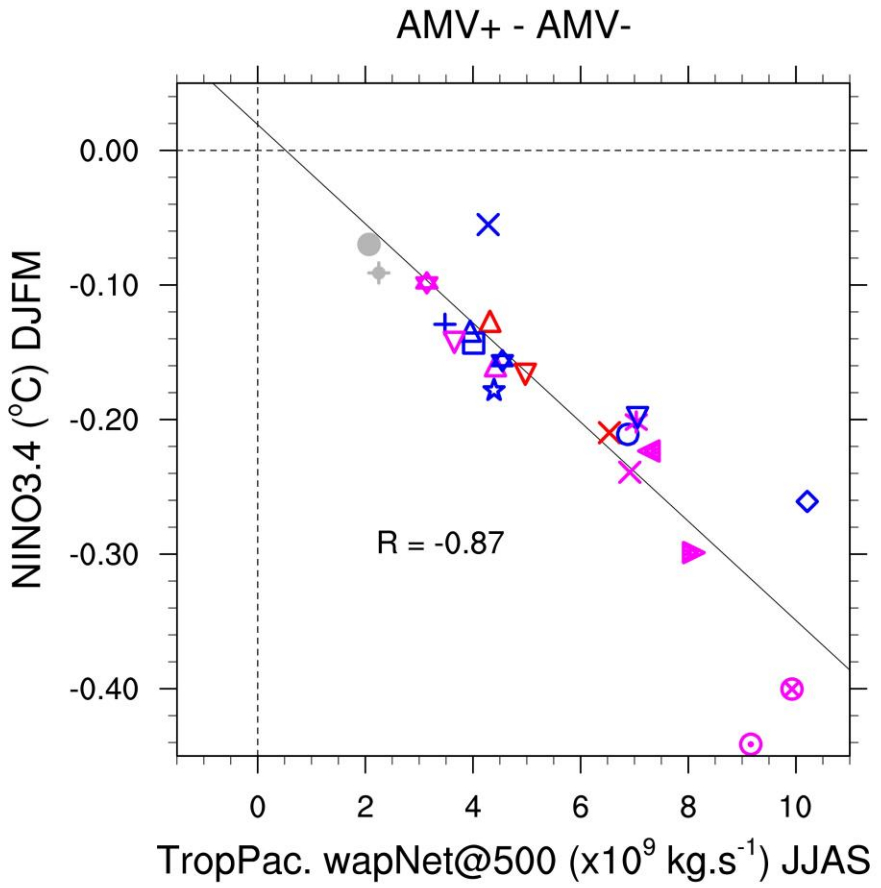


VS

JJAS – wap@500hPa



(wap: vertical air transport on pressure coordinates)



MMM = Multi Model Mean

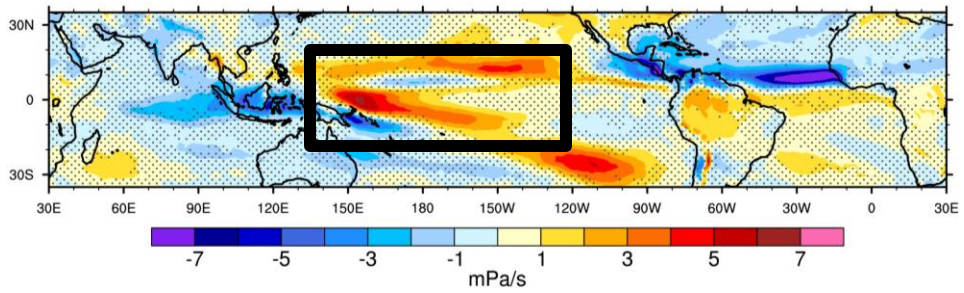
(vertical transport = positive downward)

2) Is the Pacific subsidence linked to ascendance over tropical regions?

Trop. Pac. subsidence almost completely compensated by ascendance within tropics ✓

MMM AMV+ - AMV-
(10yr averaged ensemble mean)

JJAS – wap@500hPa



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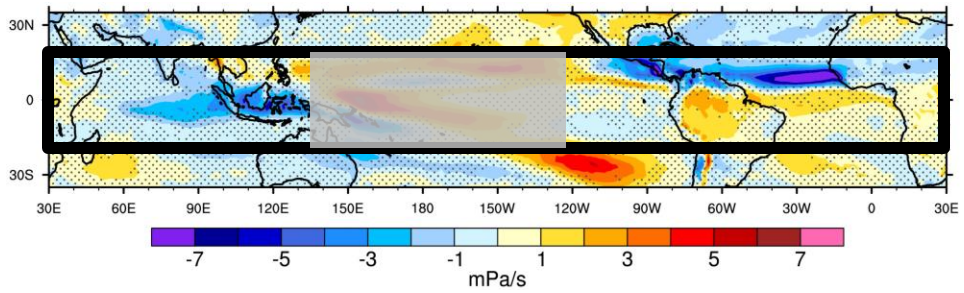

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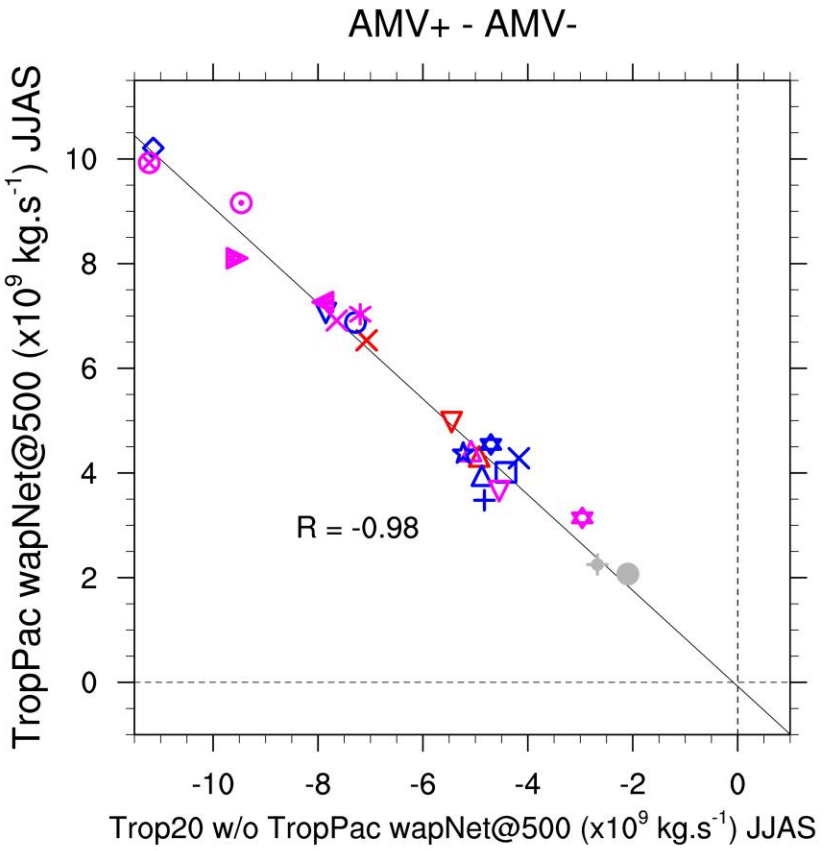

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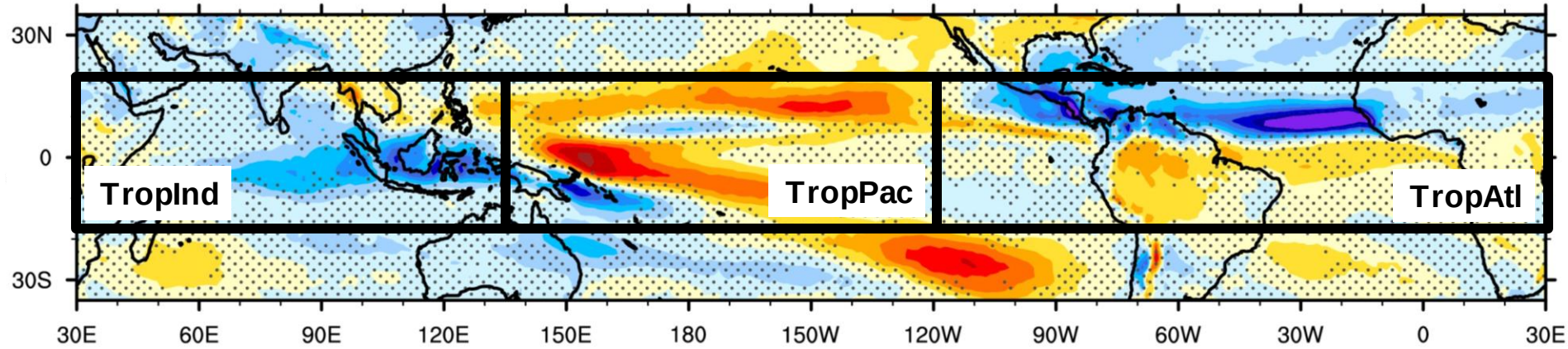
$$Var\left(wap_{Pac}^{500}\right) \sim Var\left(wap_{Ind}^{500}\right) + Var\left(wap_{Atl}^{500}\right) + COV$$



(wap: vertical air transport on pressure coordinates)

(positive vertical transport = downward motion)

3) Which region dominates the ascendance anomalies?

$$Var\left(wap_{Pac}^{500}\right) \sim \boxed{Var\left(wap_{Ind}^{500}\right)} + Var\left(wap_{Atl}^{500}\right) + COV$$

69% **19%**

MMM AMV+ - AMV-
(10yr averaged ensemble mean)

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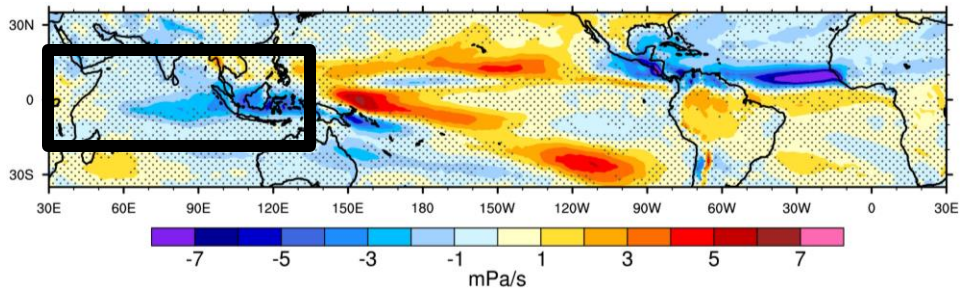

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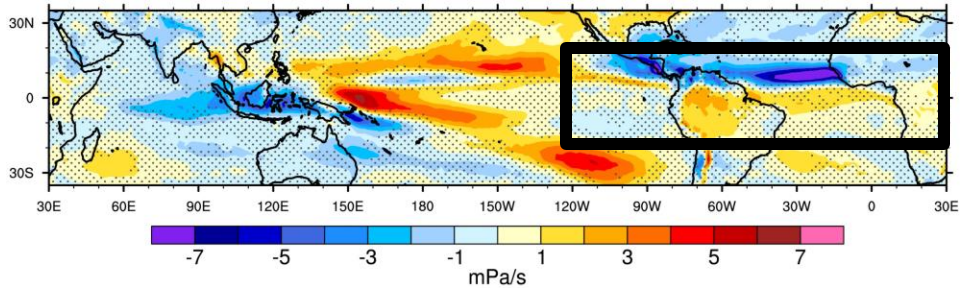

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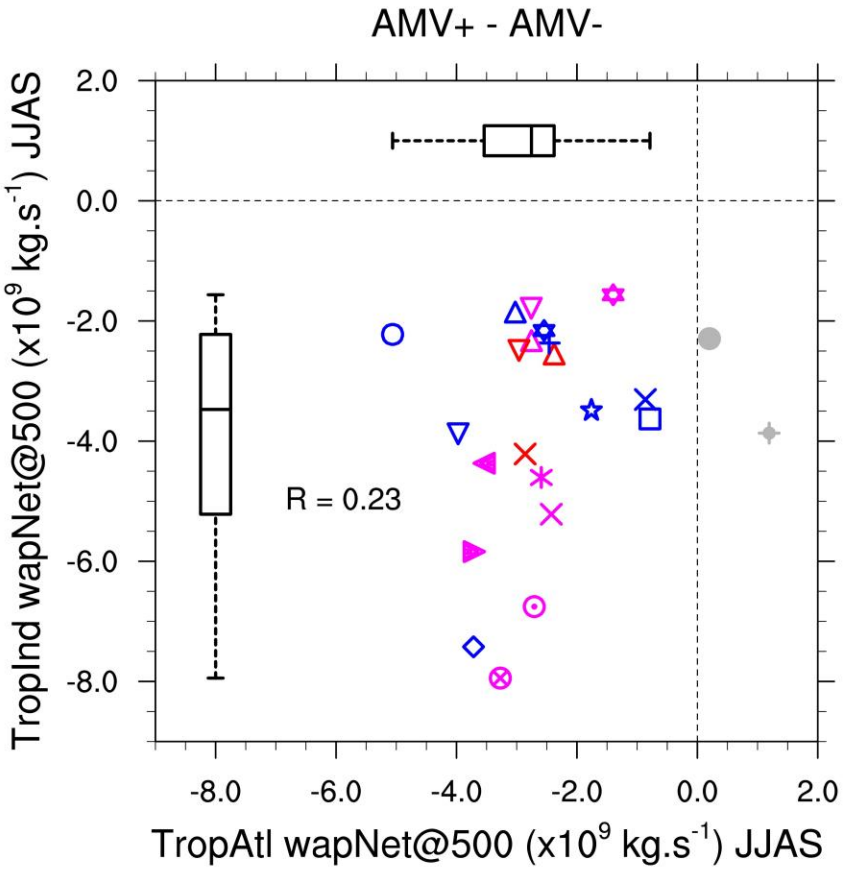

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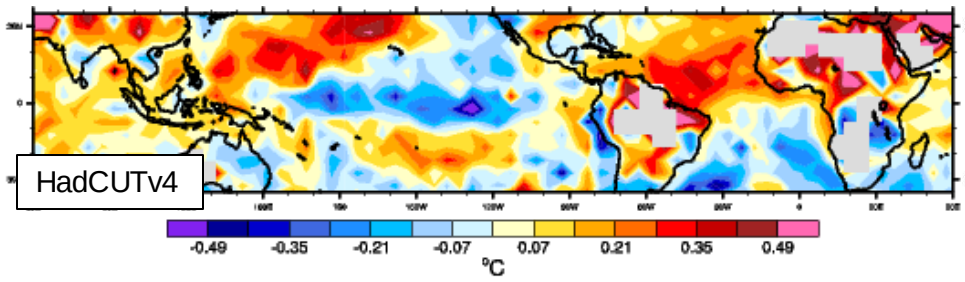

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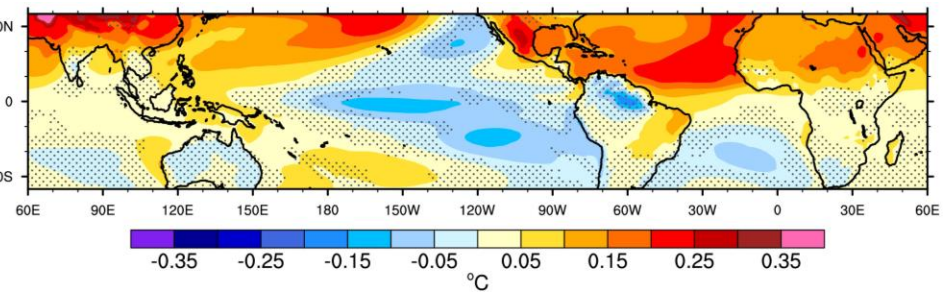

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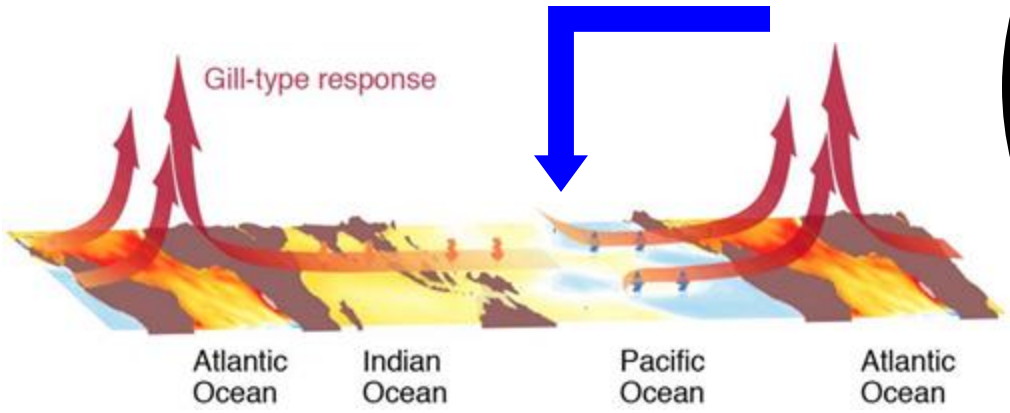

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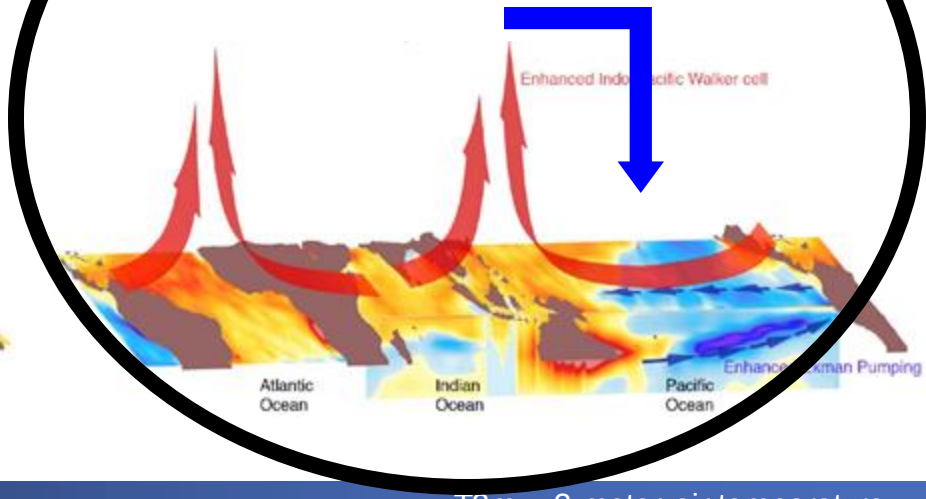

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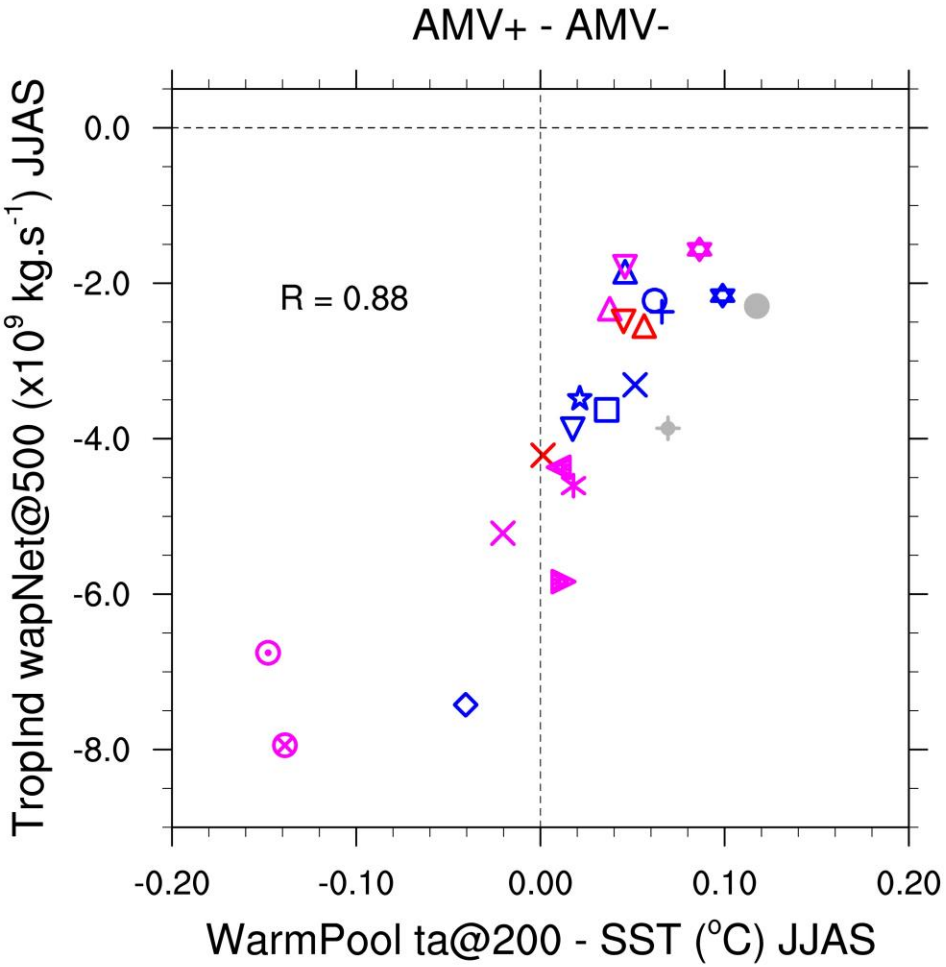
Origins of spread in TropInd ascendance?

Trop. Ind. ascendance linked to lapse rate over WarmPool



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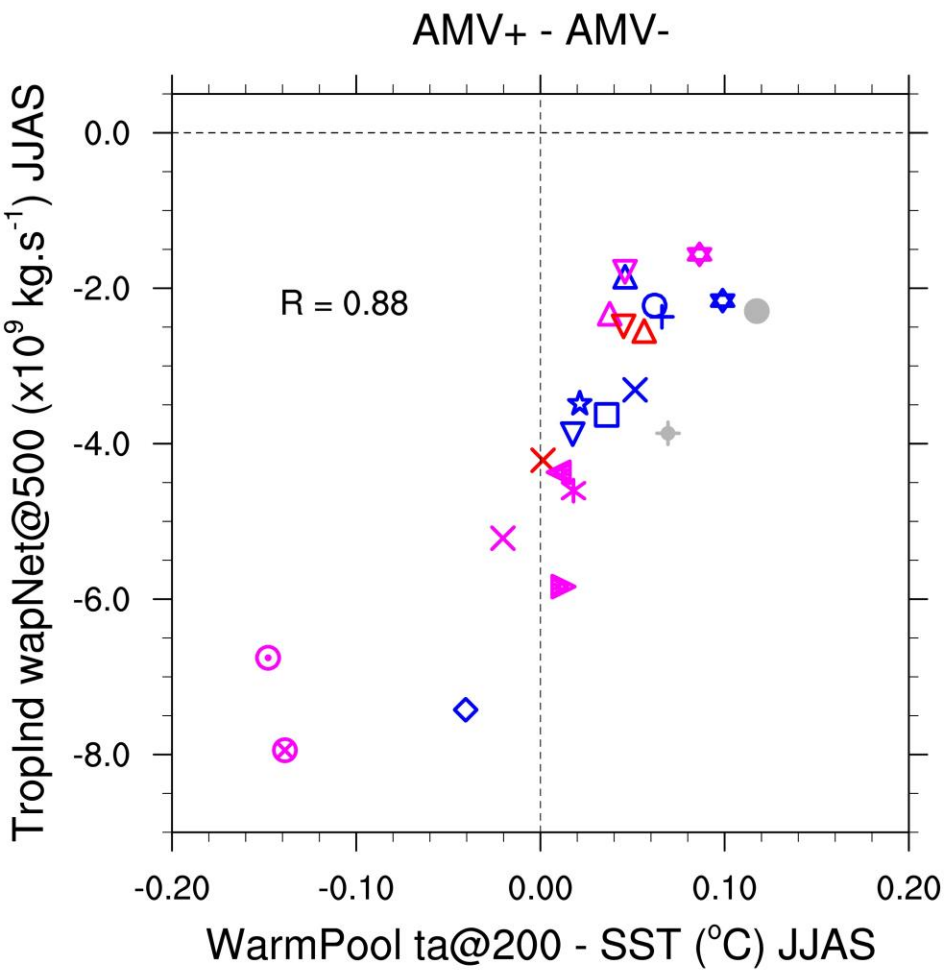

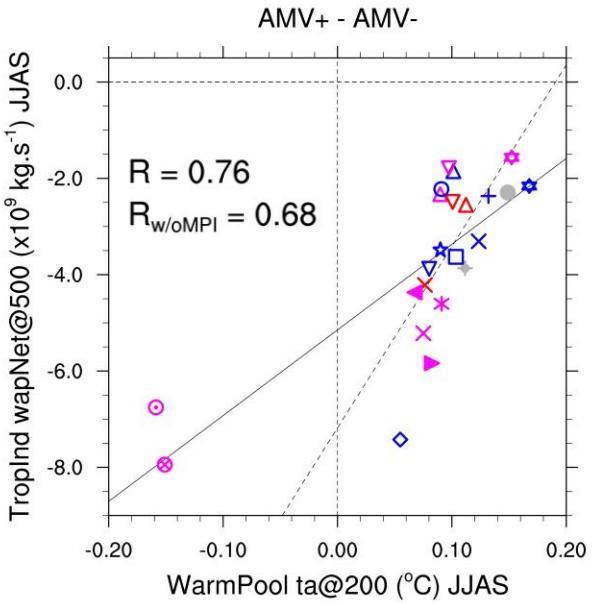

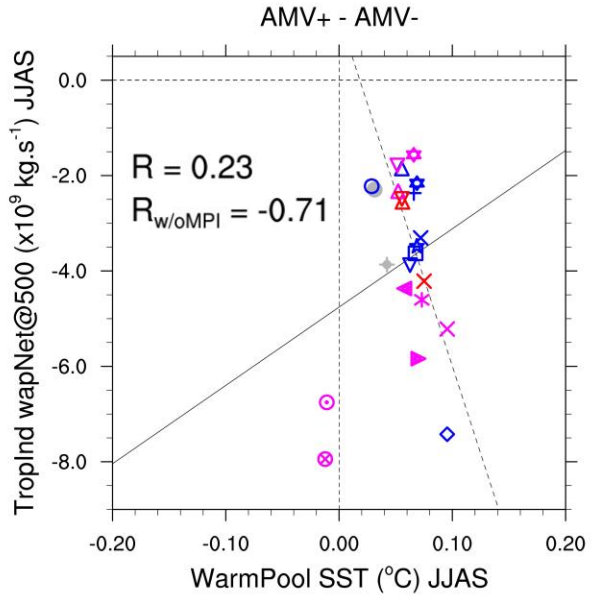

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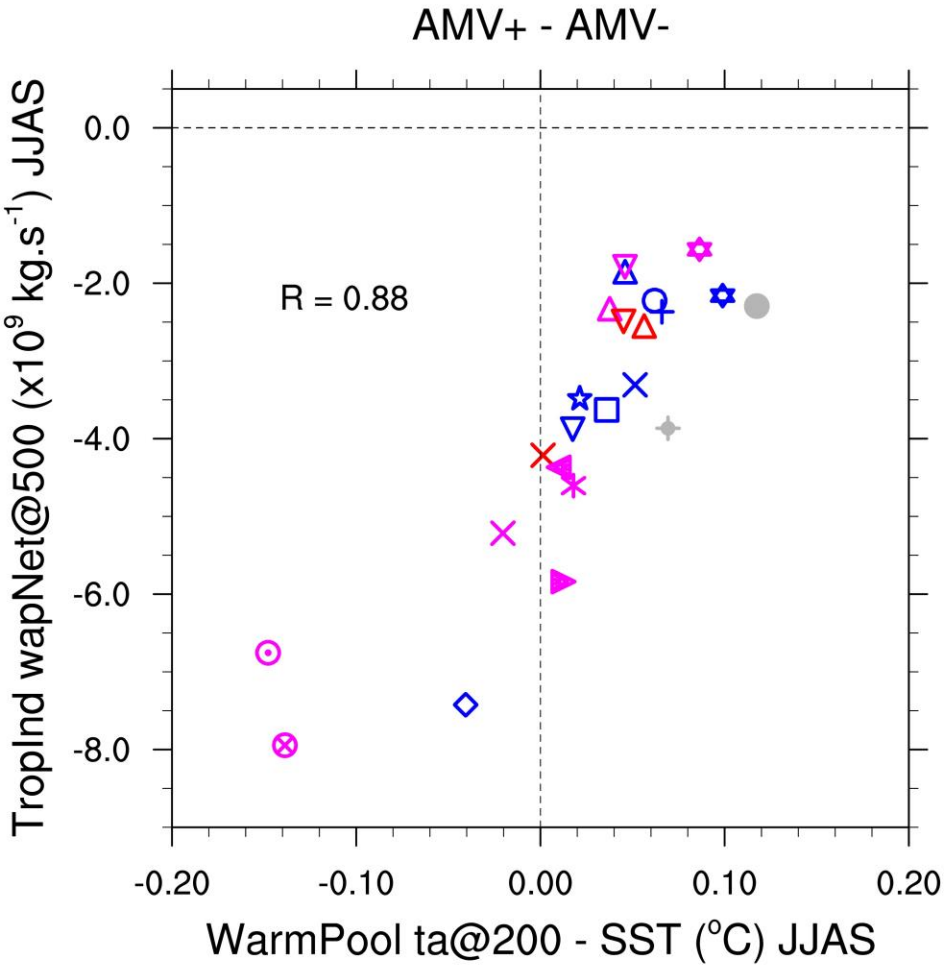
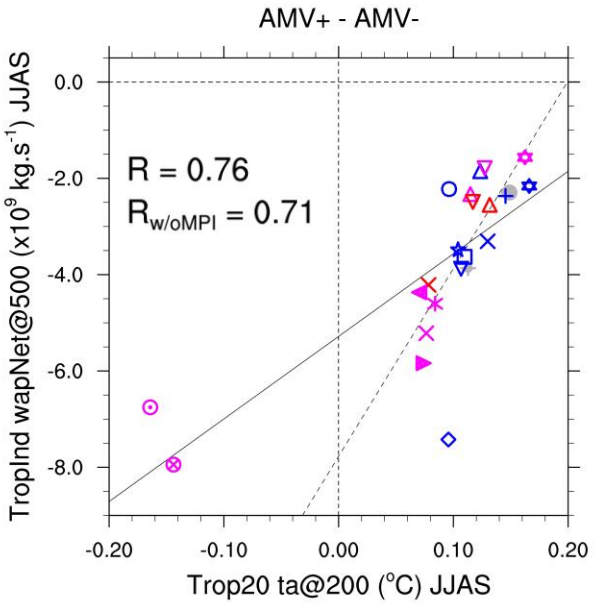
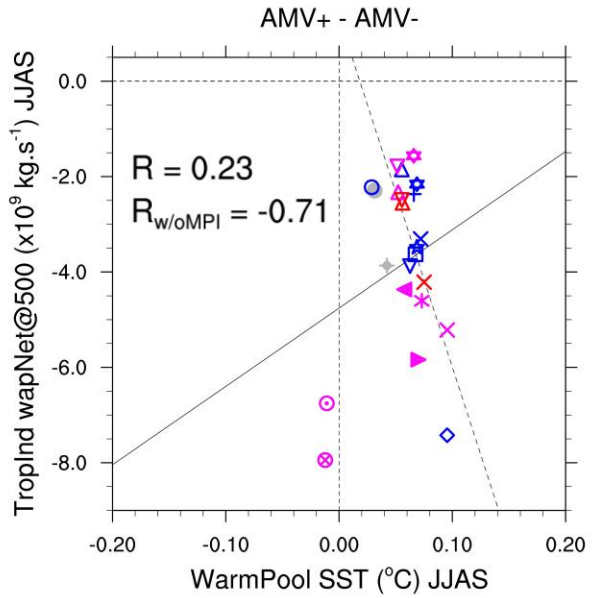






(positive vertical transport = downward motion)

Origins of spread in tropical upper troposphere temperature?

- **Mean tropical troposphere temperature profile** often considered in a moist-adiabatic equilibrium with **mean tropical SST**.

- But regions with no convection (e.g. cold SST regions) are not directly connected to upper troposphere.

- Sobel et al. (2003) proposed to use **precipitation weighted mean SST $\boldsymbol{PSST}$**:

$$\mathrm{P}SST = \frac{\langle Pr \times SST \rangle}{\langle Pr \rangle}$$

where $\langle Pr \rangle$ is the sum over the tropics (20ºS-20ºN) of the precipitation.

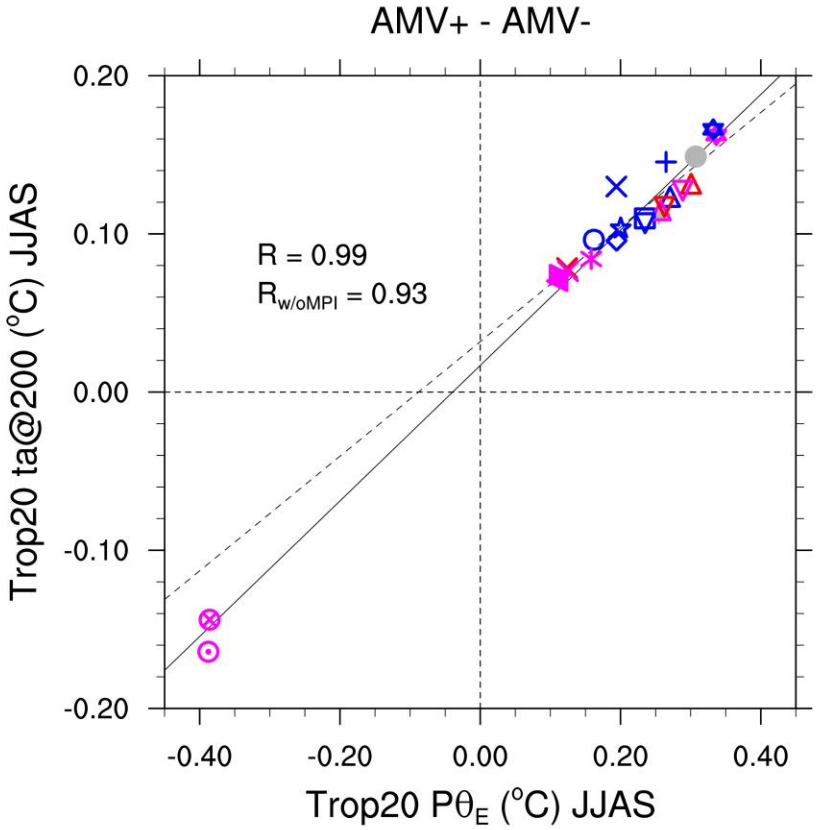
- Here, we generalized this formula to also take into account changes over land by using the surface **equivalent potential temperature $\boldsymbol{\theta_E}$**:

$$\mathbf{P}\boldsymbol{\theta_E} = \frac{\langle \boldsymbol{Pr} \times \boldsymbol{\theta_E} \rangle}{\langle \boldsymbol{Pr} \rangle}$$

Origins of spread in tropical upper troposphere temperature?

$$\mathrm{P}\boldsymbol{\theta_E} = \frac{\langle \boldsymbol{Pr} \times \boldsymbol{\theta_E} \rangle}{\langle \boldsymbol{Pr} \rangle}$$

$$(\mathrm{P}\boldsymbol{\theta_E})' = \boldsymbol{f_{Pr'}}(\boldsymbol{Pr'}, \overline{\boldsymbol{\theta_E}}) + \boldsymbol{f_{\theta_E'}}(\overline{\boldsymbol{Pr}}, \boldsymbol{\theta_E'}) + \boldsymbol{Res}$$



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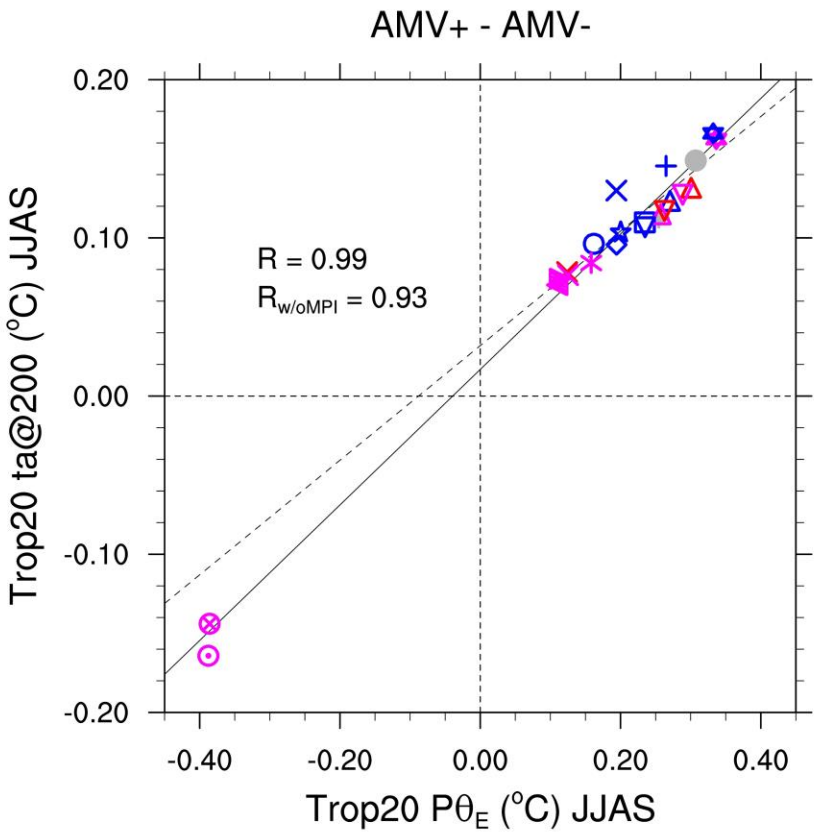
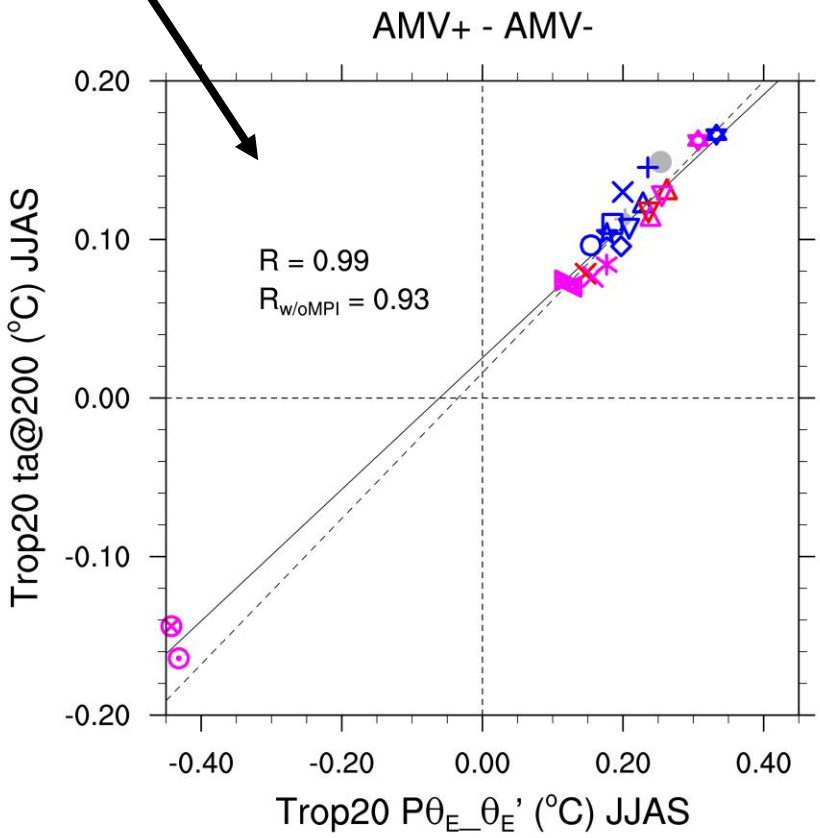
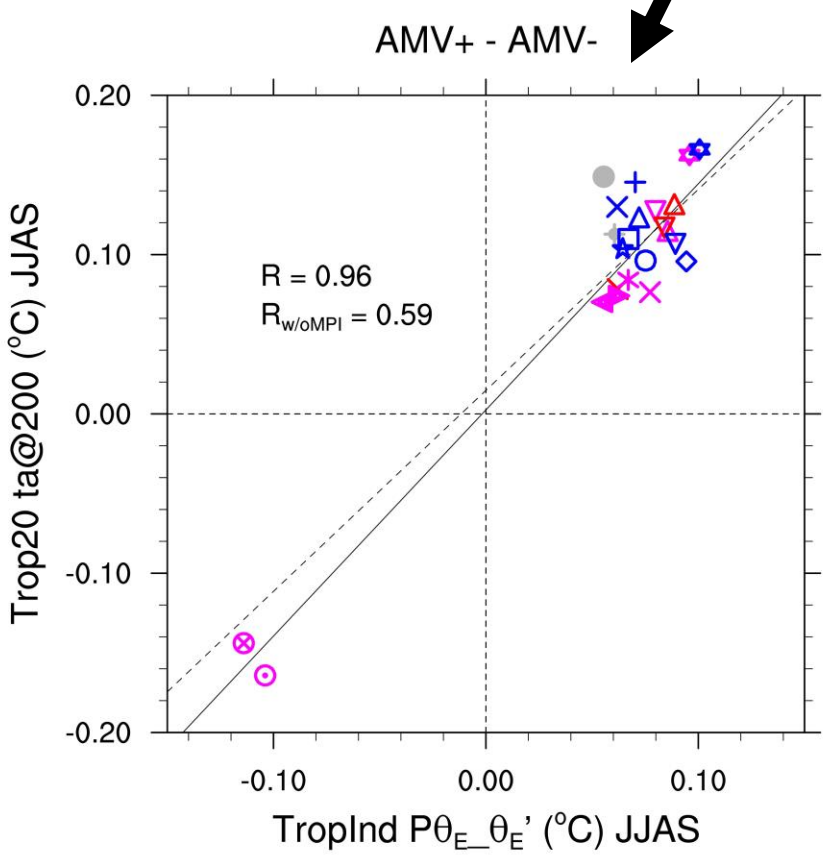
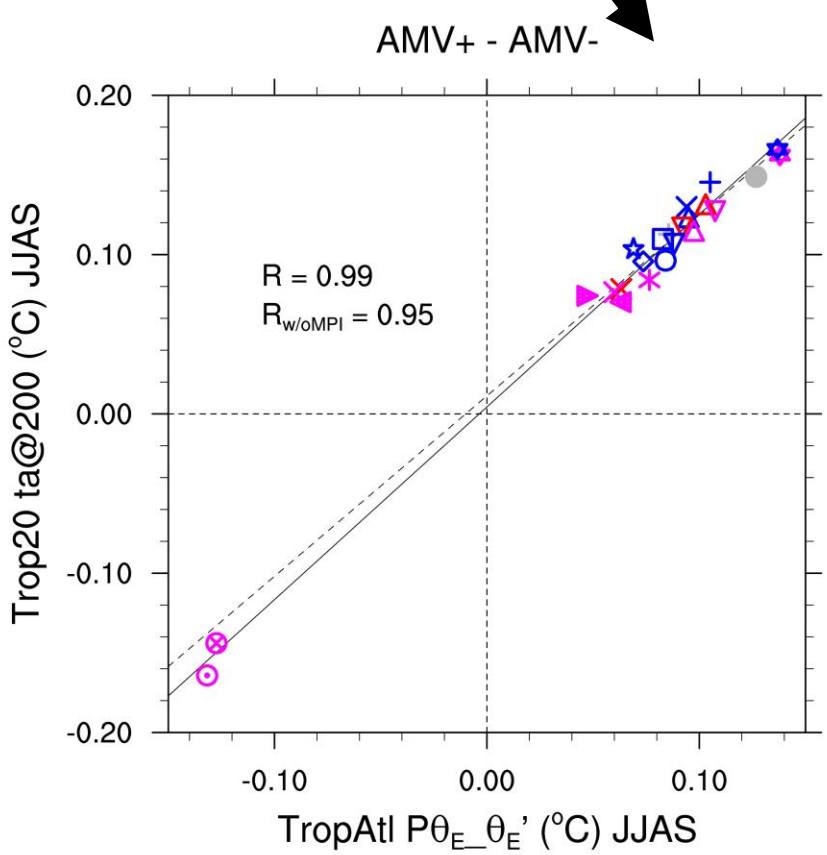




Origins of spread in tropical upper troposphere temperature?

$$\overline{\mathrm{P}}\theta'_E = \frac{\langle \overline{Pr} \times \theta'_E \rangle}{\langle \overline{Pr} \rangle} = \frac{\langle \overline{Pr} \times \theta'_E \rangle_{Ind}}{\langle \overline{Pr} \rangle} + \frac{\langle \overline{Pr} \times \theta'_E \rangle_{Pac}}{\langle \overline{Pr} \rangle} + \frac{\langle \overline{Pr} \times \theta'_E \rangle_{Atl}}{\langle \overline{Pr} \rangle}$$





To summarize

- Idealized AMV experiments confirm the observed link between AMV and tropical Pacific:
  - 23/23 simulations show tropical Pacific cooling in response to AMV warming.

- Large inter-model spread in Trop. Pac. cooling response to a given AMV warming
  - factor 5 among models

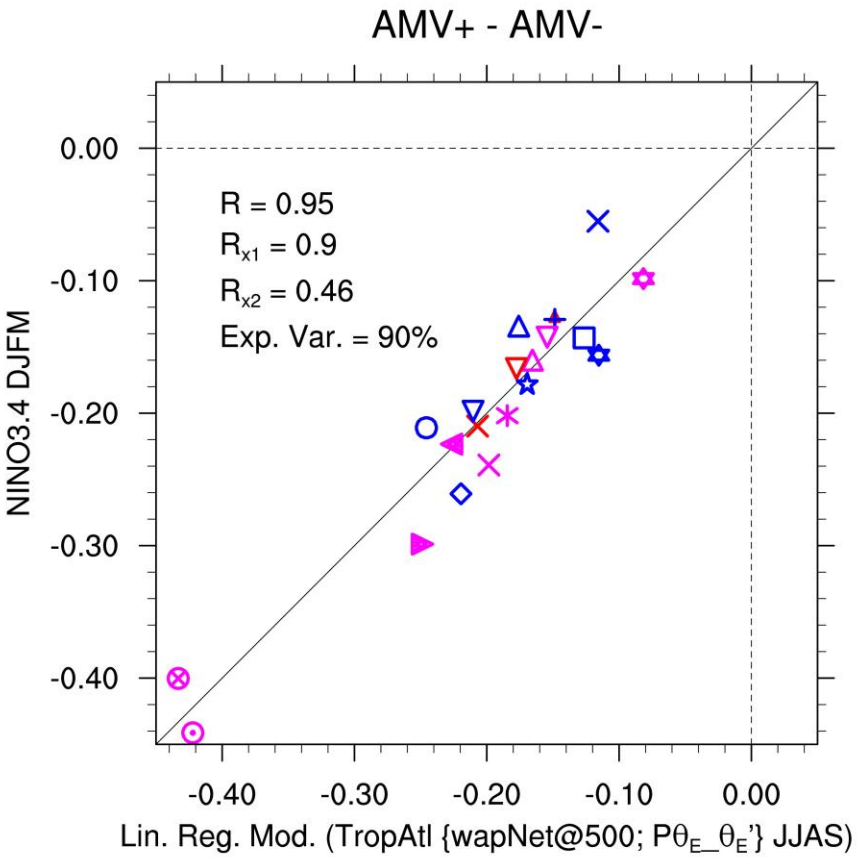
- Spread coming from Trop Pac. subsidence response in summer:
  - 19% Trop. Atl. ascendance
  - 69% Trop. Ind. ascendance.

- Trop. Ind. ascendance spread linked to upper troposphere response
  - dictated by Trop. Atl. temperature conditions: $\frac{\langle \overline{Pr} \times \theta'_E \rangle_{Atl}}{\langle \overline{Pr} \rangle}$

2 variables control the spread in the Trop. Pac. response:

- **Trop. Atl. ascendance (wap@500)**
- **Trop. Atl. injection of moist static energy ($\overline{\mathrm{P}}\theta'_E$)**

To summarize



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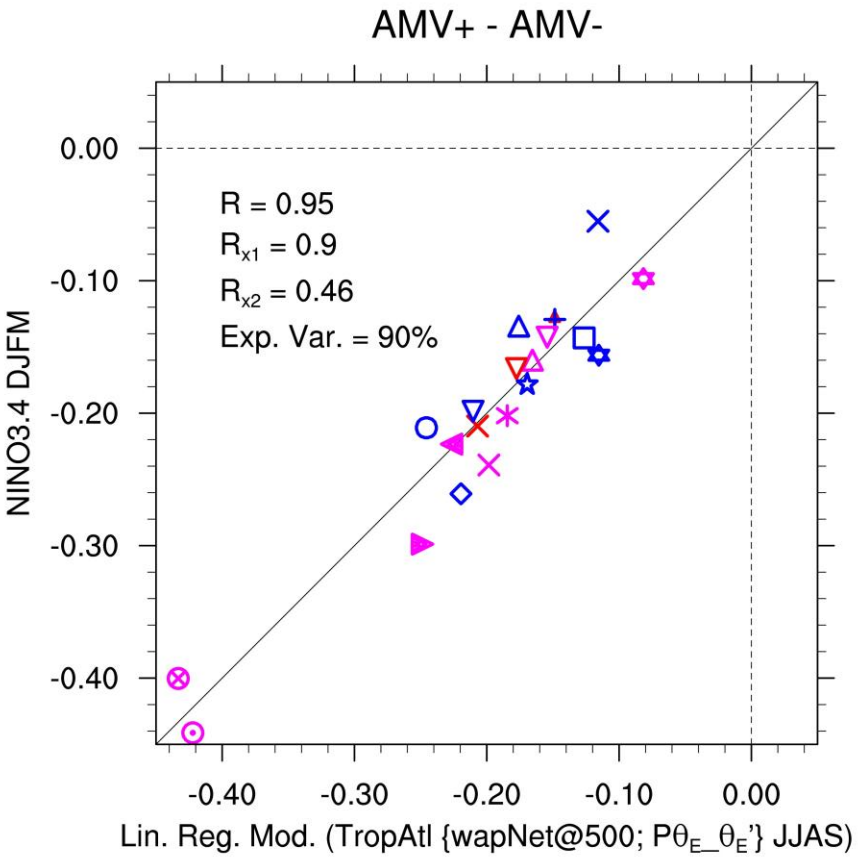

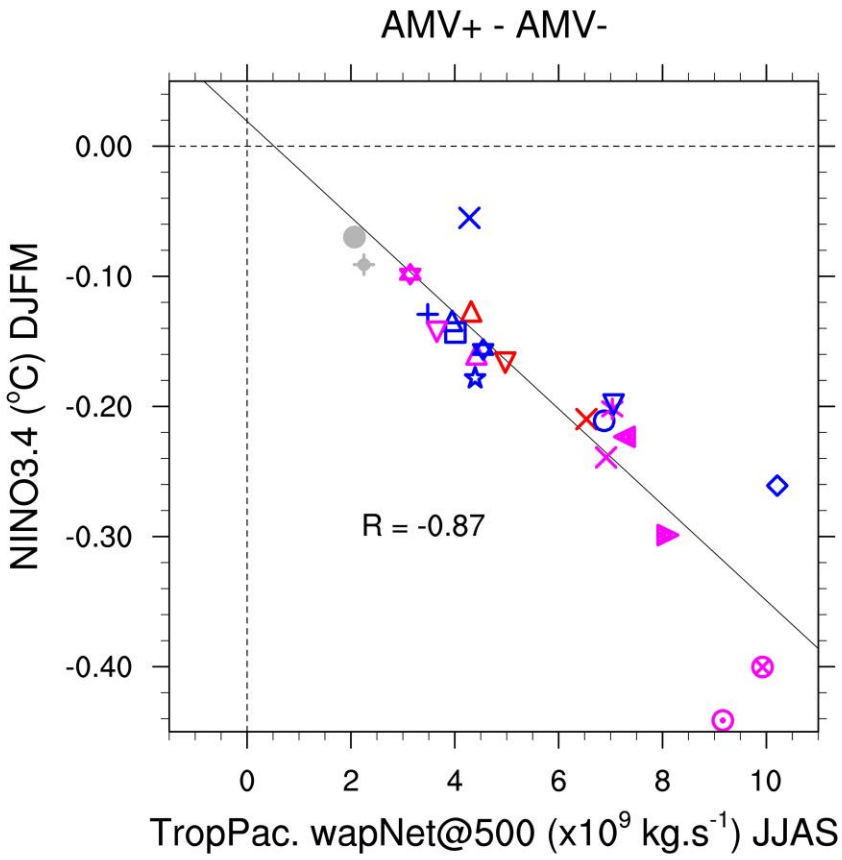

2 variables control the spread in the Trop. Pac. response:

- **Trop. Atl. ascendance (wap@500)**
- **Trop. Atl. injection of moist static energy ($\overline{P}\theta_E'$)**

Stay home messages

1. **Everything is driven by the Atlantic** 🙂

2. **We need to understand the difference of model responses over tropical Atlantic**

Thank you!